Benchmarking and Validation of IR Signature Programs: SensorVision, CAMEO-SIM and RadThermIR

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ABSTRACT

Computer programs for prediction of optical signatures of targets in background are valuable tools for several applications such as study of new platform concepts, new coatings, and assessments of new sensor technology and development of tactics. This paper covers a validation activity of three commercial optical signature prediction programs available at FOI: SensorVision, CAMEO-SIM and RadThermIR. As targets two flat panels with different emissivity in thermal IR was used, one close to unity and the other approximately 0.5. The panel signature was measured for a complete 24-hour period and radiance data for the panels were collected as well as supporting data consisting of weather data and contact temperature data.

All three simulation programs were used to predict the radiance and the physical surface temperature of the panels. The simulation results were compared with the measurement results and they show considerable agreement. Some deviations were observed and they are discussed in the paper. The largest deviations between measurements and modelling results are most likely related to weather parameters, such as wind speed, wind direction, cloudiness, etc. Generally, the low emissive panel was harder to predict than the paint panel, and MWIR was harder to predict compared to LWIR. The work gave valuable experience of the use of the programs.

1.0 INTRODUCTION

Computer programs for prediction of optical signatures of targets in backgrounds are valuable tools in the process of designing different platforms and the study of new concepts with respect to low signature capabilities. In many cases it is necessary to treat the background in as much detail as the targets. There are other important reasons for the use of prediction programs, e.g. to improve the understanding of the signature processes; as a tool for assessment new sensor technology; for development of tactics; etc. All the applications raise different requirements on the signature prediction programs.

At FOI several commercial programs have been used for optical signature predictions. Some of them have been used for quite some time and others are more recently acquired. Validation of the programs is an important task that has to be fulfilled. The validation work is also an excellent way of improving the knowledge of the program and helps the development of efficient methods for the actual use of the programs. Many of the programs require huge amounts of input parameters and the work needed to properly assign values to these parameters should not be underestimated. Validation of commercial programs is of course being performed at other institutions (Ref 4, Ref 7, Ref 8, Ref 11 and Ref 16), and the work at FOI is to be seen as a complement to these previously reported validations. An earlier validation at FOI has also been reported Ref 1.

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This report covers a validation activity of three commercial optical signature prediction programs available at FOI: SensorVision, CAMEO-SIM and RadThermIR. SensorVision is a VEGA-based application that produces IR scenes in real time with a certain amount of simplifications in order to obtain the real time capacity. CAMEO-SIM is an advanced IR program aiming at producing high fidelity physics based images originally applied to camouflage assessments. RadThermIR is a 3-dimensional (with some restrictions) heat transfer program that uses Finite Difference Methods to predict the temperature distribution for a target and after that also predict the IR radiance. All three programs have their applications and they therefore complement each other. FOI has previously showed how RadTherm can be used for improving the target signature modelling of SensorVision, see Ref 6. The programs will only be shortly described in this paper.

In this work simple targets were chosen and the background was treated in the simplest way like a flat plane. The targets consisted of two panels with quite different surface emissivity, one was close to unity and the other was approximately 0.5. The panel signature was studied for a complete 24-hour period to emphasise the influence of a varying solar irradiance and sky cloud coverage. By using short time steps for the study, the dynamic behaviour could be monitored. An experiment was set up to collect both radiance data for the panels as well as supporting data consisting of weather data and contact temperature data.

Swedish normal time (not daylight-saving time) is used consistently through the paper.

2.0 EXPERIMENTAL

2.1 Panels and reference

The purpose of the panels was to provide simple targets to study fundamental signature effects. The panels consisted of different layers that formed a flat surface of 1 x 1.2 m^2. Thereby, the heat conduction problem became essentially one-dimensional. The surface scattering was also simplified since no internal reflections could occur between different parts of the target. One of the layers in the panel was a heat-foil to enable elevated temperatures. At the back of the panels there was a comparatively thick layer of insulating PVC foam, Divinycell, to minimize the heat flow through the back side of the panel. This decreases the power consumption when heating the panels and simplified the heat conduction problem. However, for the work presented here, the panels were passive and not heated by the heat-foil. The layers were attached to each other, either by glue or by two-face tape. A cross-section of the panels is shown in Figure 1. The panels were built by Saab Barracuda AB.

The two panels used for this experiment were coated differently. One of them was painted with standard Swedish dark green camouflage paint. The other one had a low emissive foil attached to the front surface with two face tape. The foil was also dark green but with a slight difference in colour compared to the paint. The panels were mounted on stands of Aluminium, see Figure 1.

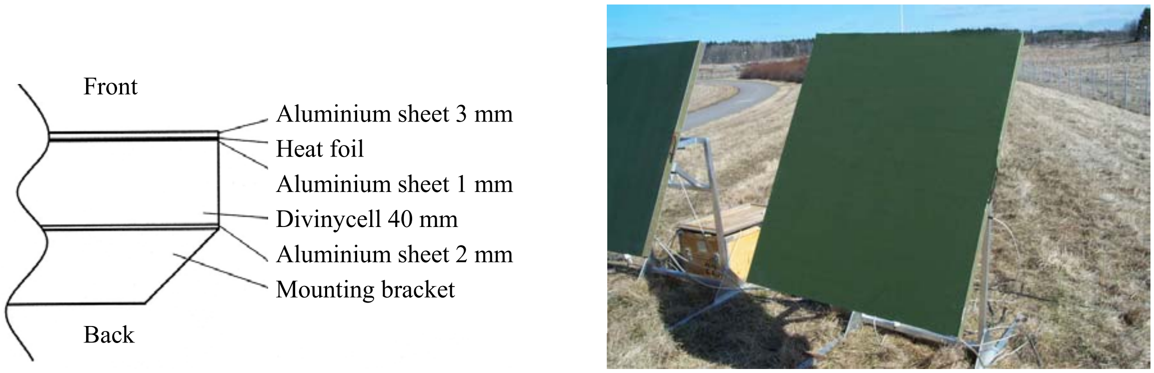

Figure 1 Cross section of the panels (left) and the two panels on their stands (right)

On each panel there was a Pt 100 temperature sensor mounted inside the front Aluminium sheet, close to the front surface. The sensor has a 4-wire connection to a chassis connector in a box on the back of the panel to enable monitoring and logging of the panel temperature. The Pt100 sensors were calibrated in lab. The uncertainty was estimated to be 0.04 ºC. The temperature probes were connected to a logger AAC-2 which had an estimated uncertainty of approximately 0.1 ºC.

The ambient air temperature blackbody reference is a field blackbody consisting of a conical cavity. A fan ensure that the reference adapt to air temperature. The reference had a Pt100 sensor installed to enable monitoring of the temperature and the temperature was logged on the same logger as the panels.

2.2 Instrumentation

A Thermovision System 900 with two cameras were used, one long wave (LWIR) with filter LPL (7.5-12µm) and one mid wave (MWIR) with filter Y02 (3.5-5µm). The spectral response for the camera systems are shown in **Figure** 2. The cameras use a scanning technique with one detector and can therefore be radiometrically calibrated, with a result of 272x136 pixels. The field-of-view of the camera lenses were 20º. Images were collected and stored automatically every minute. The cameras were mounted on a tripod and the controlling electronics and storage devices were placed in a van. As weather protection the tripod was covered with a plastic tarpaulin.

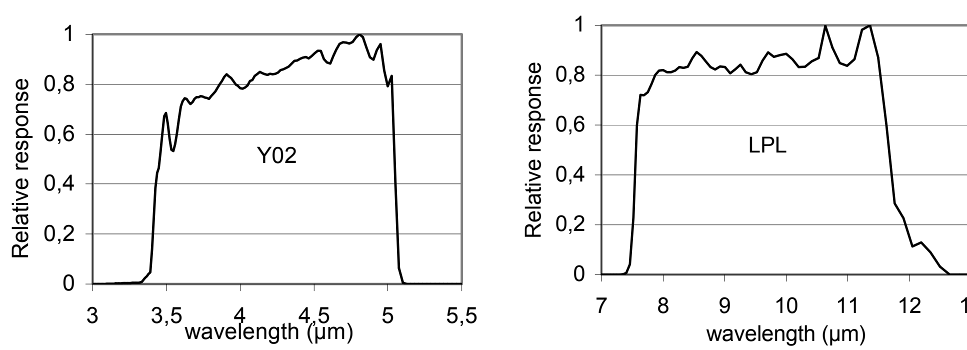

Figure 2 Spectral responses of the MWIR (Y02) and LWIR (LPL) Thermovision cameras.

The weather station used was a Vaisala Milos 500, equipped with different kinds of weather sensors and additional radiation sensors from Kipp & Zonen. Values were recorded every minute during the measurements. The weather station was placed in close proximity to the panels and started logging 24 h before the radiance measurements stated.

2.3 Measurements

The measurements took place at the FOI site in Linköping. The panels and sensors were placed on a bank covered with grass. The sensors were looking horizontally at the panels in a direction of 76º relative to north. The panels were placed 17.6 m from the sensors and the surface normal of the panels had a direction of 256º relative to north and an elevation of +30º.

The measurements were made on 8-9 April 2003, continuously for a 24-hour period. After the measurements the IR-pictures were calibrated to yield the radiance according to the filter and detector combination used. The Matlab-based evaluation software IR-Eval developed at FOI was used to do this. The radiance was corrected for atmospheric transmission losses, which gave the radiance at the panel surfaces. The transmission was estimated with Modtran and turned out, as expected, to be practically negligible. An average value of the radiance was calculated for each panel as a function of time.

2.4 Results

The apparent temperature images are a good way of illustrating different phenomena, see examples in Figure 3. The images show how the contrast between the panels and the background varies with time of day and surface material.

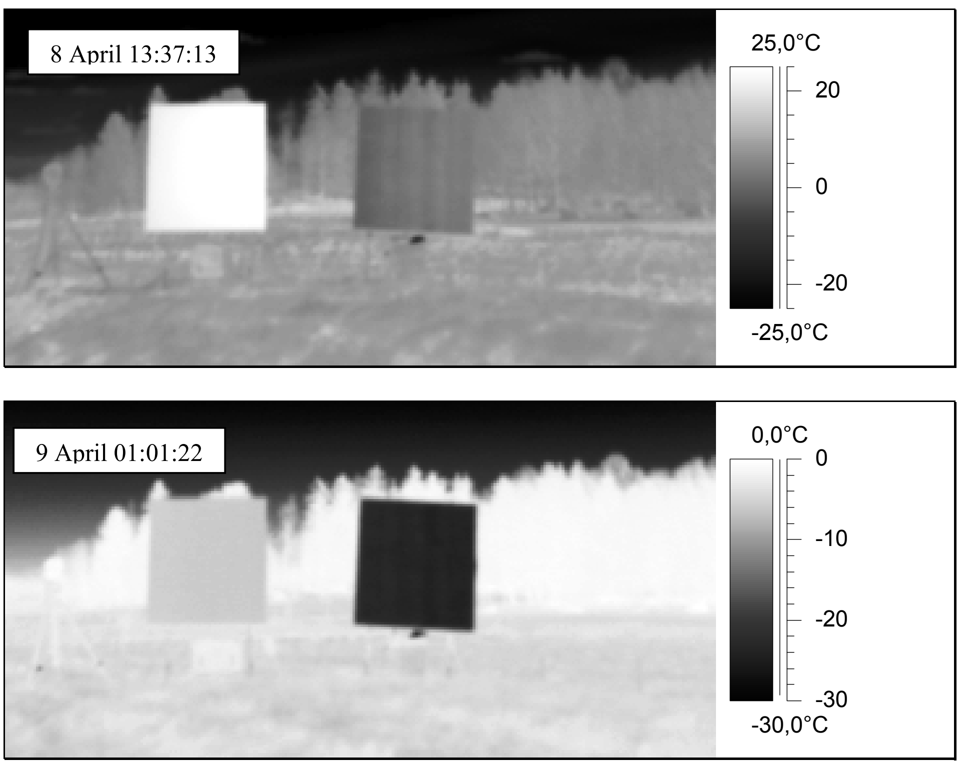

Figure 3 Images of apparent temperature in LWIR of the panels for day and night time. Paint panel to the left and foil panel to the right. Please note the different temperature scales.

The determined calibrated apparent radiance values of the panels are shown together with the simulation results in the simulation results section of this paper. The variations with the time of day are very obvious.

It is also clearly shown how the sun irradiance differences between 8 April (sunny) and 9 April (cloudy) affects the radiance of the panels. The foil panel radiance makes dramatic shifts in radiance during the night which most probably is an effect of changing cloudiness. This was confirmed by the long wave sky irradiance measurement (un-calibrated) that was made with the weather station.

In order to determine the uncertainty of the radiance measurements and the following data processing, comparisons were made between contact temperature measurements and Thermovision results for the ambient air temperature reference. The measured contact temperature of the ambient air temperature reference was used to calculate the blackbody radiance for the two Thermovision wavebands in LWIR and MWIR. It appeared to be a quite systematic difference between the measured and calculated blackbody radiance over the 24-h period. The most likely explanation is that there were calibration offset errors in the Thermovision system. From the stable night period the radiance offsets (measured minus calculated) was found to be +0.96 W/(sr m^2) for LWIR and -0,091 W/(sr m^2) for MWIR. From the estimated uncertainty of the measured contact temperature of the ambient air temperature reference together with the emissivity of the reference, the uncertainty in the calculated radiance was determined. For LWIR it was found to be 0.1 W/(sr m^2) and for the MWIR 0.006 W/(sr m^2).

Another clear deviation for the radiance ambient air reference occurred early in the morning (about 06.00) when the sun elevation was very low. Probably the Thermovision lenses were sun lit which introduced stray light and an extra radiance contribution. The reader should bear in mind both the constant calibration offset and the morning stray light disturbance when studying the deviations between simulations and measurements in later sections of this paper.

The weather data recordings started 24 h before the radiance measurements to provide input for the thermal calculations. During the 8^{th} the sky was clear and the weather sunny. The 9^{th} the sky was cloudy and at about 13:00 it started to rain mixed with snow. Soon after that the experiment was stopped.

The logged contact temperatures are shown together with the simulation results in a following section on simulation results. The panels reached a considerable temperature on the 8 April even though they were only heated by the sun. The 9^{th} was cloudy and not clear as the 8^{th} and this resulted in a much lower afternoon temperature. The panel with low emissive foil showed higher temperatures than the painted panel. The reason is that the heat loss trough radiation is lower for a low emissive surface compared to a high emissive one.

3.0 SIMULATION SOFTWARE

A number of coupled physical phenomena have to be considered in modelling of IR signatures. Modelling of heat transfer, atmospheric effects and radiometry are all needed in order to calculate the in-band radiance detected by an IR sensor. There are a large number of models and methods, with varying degrees of complexity and accuracy, for calculating the individual physical processes involved in modelling of IR signatures from targets and backgrounds. In this section we will briefly present some features of the commercial IR signature simulation software SensorVision, CAMEO-SIM and RadThermIR.

Input data to the simulation software consist of for instance material thermal and optical (spectral reflectance) data, triangulated (CAD) models for terrain and/or objects, weather data and model and rendering options. When using SensorVision or CAMEO-SIM a sensor response function should also be provided. The main output from the simulation software is radiance maps of the synthetic 3D scene or object. Calculated surface temperatures can also be obtained as output data.

Due to the great complexity involved in modelling IR signatures, the models used in commercial signature prediction programs are usually adapted to the main area of application of the program. SensorVision, Ref

14 and Ref 18, is a VEGA-based application, developed by Multigen Paradigm Inc. for simulation of IR scenes in real time. CAMEO-SIM (version 4.2),

Ref 5, Ref 8, Ref 9 and Ref 11, is a synthetic scene-generating tool developed by Insys Inc. aiming at producing high fidelity physics based images at wavelengths between 0.4-20 µm. CAMEO-SIM was originally developed for assessment of camouflage. The thermal and infrared signature modelling tool RadThermIR (version 7.0.1), Ref 17, has been developed primarily for accurate thermal modelling of vehicles.

In order to exemplify differences between the three simulation software, we have listed some features of the software in Table 1. In SensorVision a number of simplifications and approximations have been used in the implementation of the radiation transport equation in order to reach real time performance (see Ref 3). A more accurate solution of the radiation transport can be obtained by using CAMEO-SIM. A major difference between RadThermIR and the scene simulation programs SensorVision and CAMEO-SIM is that RadThermIR models three-dimensional thermal conduction while SensorVision and CAMEO-SIM use one-dimensional conduction models. This makes it possible to model internal heat sources, such as engines in vehicles, more accurately with RadThermIR.

Table 1 Examples of differences between simulation software

	SensorVision	CAMEO-SIM	RadTherm IR
Dimensions in heat conduction	1D	1D	”3D” + internal sources (finite difference)
Real time	Yes	No (but depends on method)	No
Rendering and radiometric solution	Simplified ray tracing, simplified radiometry	Ray tracing with MonteCarlo etc. Accurate radiometry	Ray tracing
BRDF	No, but specular lobe	Yes	No, but specular lobe
Weather history in thermal solution	No	Yes	Yes
Atmospheric modelling	MOSART (isotropic atmosphere)	MODTRAN4 (3D parameterisation)	No (but sky irradiance according to Subarctic summer model)
Interaction between objects	No	Radiometrically, thermal shadowing	Thermally and radiometrically
Scene simulation	Yes	Yes	”No, not in general”

4.0 SIMULATIONS

In this section we briefly present some thermal and optical material data for the panels, which are used as input data to the IR simulations. Some important software specific inputs are also given.

4.1 Case definitions and input data

An important quantity in radiometric models is the spectral reflectance. Some models and software also have the ability to treat an angular dependence in the reflectance, through a bidirectional reflectance distribution function (BRDF) for instance. In the simulations presented in this report the panel surfaces are assumed to be diffuse and therefore no angular dependence (or specular reflection) is considered. The reflectance of the two considered panel coatings has been measured at visual and IR wavelengths. At IR wavelengths Hemispherical Directional Reflectance (HDR) data are available and the HDR for 8º incidence angle was used as an estimate for the spectral reflectance used in the simulations.

Thermal material data, which are used in the simulations, are presented in Table 2. The solar absorptivity was calculated from measured reflectance data at the visual wavelengths, weighted against the solar spectral irradiance at sea level (for 1 air mass), Ref 19. The thermal emissivity was estimated from the measured Hemispherical Directional Reflectance (HDR) data. The data for specific heat, conductivity and density for aluminium have been taken from Ref 12 and the data for Divinycell are data provided by the manufacturer in Ref 2. No effort has been made to find accurate values of the characteristic lengths, which is a parameter in thermal convection models, and these values should be seen as very rough estimates.

Table 2 Thermal material parameters used as common input data in the simulations

	Paint	Foil	Aluminium	Divinycell
Solar absorptivity	0.805	0.7		
Thermal emissivity	0.8	0.4		
Characteristic length	1 m	1 m		
Specific heat			0.884 kJ/kg/K	1.9 kJ/kg/K
Conductivity			201.073 W/m/K	0.03W/m/K
Density			2770.09 kg/m^3	48 kg/m^3

4.2 Program specific inputs

SensorVision and CAMEO-SIM could not handle enough thin layers to model the paint as an individual layer. Therefore, the programs were employed with a two-layer model, i.e. 4 mm Al with the specific spectral reflectance (see Section 4.1) and with a 40 cm insulating layer to simulate the Divinycell. The layer after the material model was set to simulate backside air. RadThermIR was fed with a model using 3 mm Al, a 0.5 mm layer simulating the heat foil (see section 2.1) and a 40 mm Divinycell layer. The 0.5 mm heat foil layer was used in RadThermIR with a conductivity of 5 W/mK and a specific heat of 1.0 kJ/KgK.

All software were input with the correct global positions, i.e. 58.235 deg. and longitude 15.345 deg which corresponds to the FOI site in Linköping, Sweden at a height of 75 m above sea level.

The geometric model was input as a rectangle with the dimensions 1 x 1.2 m^2. In SensorVision no terrain background was input. For CAMEO-SIM and RadThermIR a simple surface with a grass-like spectral reflectance was used to simulate the surrounding terrain. In RadThermIR, the geometry of the panel was divided into 20x25 elements, and the background terrain with 50x50 elements giving about 51000 thermal nodes in 2980 elements. The input geometries were also tilted and rotated as to meet the experimental set-up (see section 2.1) for all programs.

The employment of weather is a bit different for the three programs used. SensorVision calculates the spectral and thermal atmospheres using its internal tool MAT. In SensorVision the only way to include measured weather data is to use the "Fixed Temperature Calibration Point" parameter in the MAT tool. This means that certain weather parameters for one point in time are set. Computations were carried out in SensorVision at 15:00 and 01:00. The MAT (MOSART) model atmosphere was chosen to be "Sub Arctic Winter".

CAMEO-SIM uses the inbuilt GUI to MODTRAN (version 4.2). This means that measured weather data from the experiments are input to build up the thermal atmosphere with the measured one-minute interval, whereas the spectral atmosphere used where the "Sub Arctic Winter" standard within MODTRAN. In CAMEO-SIM version 4.2 only the direct solar radiation should be given as input, but as the weather station used could not separate the direct and diffuse components, CAMEO-SIM was fed with the total sunlight instead. Therefore, an overestimation of direct sunlight can be expected. In RadThermIR the experimentally measured weather was input, where diffuse sunlight can be calculated from the total sunlight through an inbuilt model.

Convection in SensorVision and CAMEO-SIM is handled in the same manner with characteristic length to control the convection coefficient. In RadThermIR this is handled through the McAdam's plate model given by $h = c_1 + c_2 \times v$, where v is the wind speed, c_1 = 5.7 and c_2 = 3.8.

All software were fed without a cloud coverage and with simulations ranging from 00:00 2003-04-08 to 13:00 2003-04-09.

CAMEO-SIM and SensorVision was also fed with the ThermoVision system spectral response functions noted as LPL and Y02 (see section 2.2). In RadThermIR there is no possibility to set a sensor's response function and therefore an ideal sensor was assumed with the spectral interval 3-5µm for MWIR and 8-12 µm for LWIR.

For RadThermIR the simulations were carried out using 5 min intervals and for CAMEO-SIM 15 min intervals were used. The RadThermIR model is shown in Figure 4

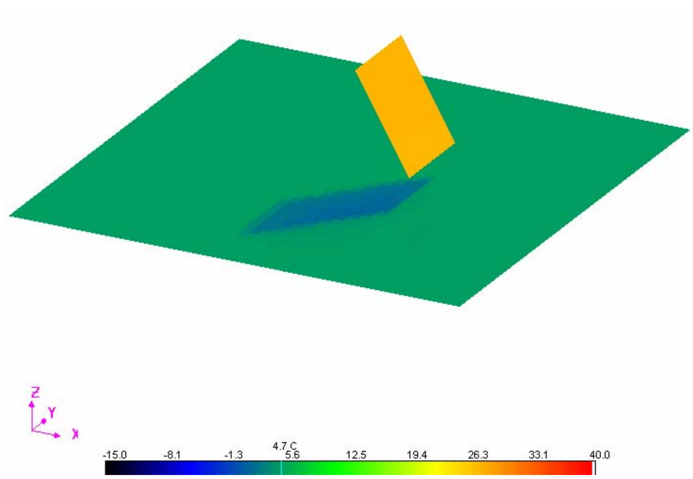

Figure 4. The RadThermIR model. Also note the dynamic shadow behind the panel.

5.0 RESULTS

In Section 4.0 we briefly described input data and how the simulations were performed with the three simulation programs. In this section we present results from simulations of the two panels. The results are presented in terms of plots of calculated radiance or surface temperature versus time. The corresponding measured quantities are also included in the plots for comparison. The results will be analysed and discussed in Section 6.

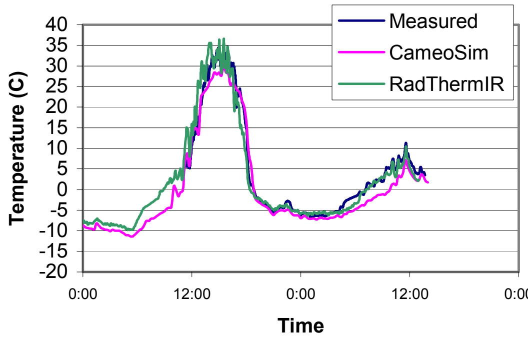

Figure 5 Comparisons of RadThermIR and CAMEO-SIM simulations for the paint panel's physical surface temperature.

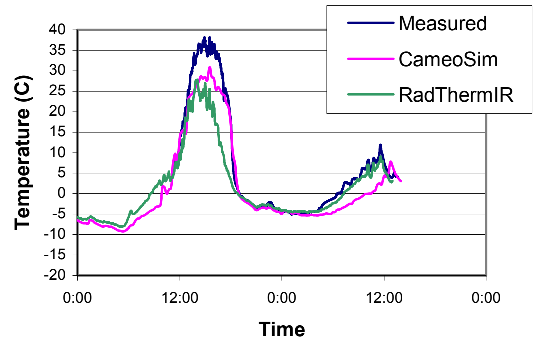

Figure 6 Comparisons of RadThermIR and CAMEO-SIM simulations for the foil panel's physical surface temperature.

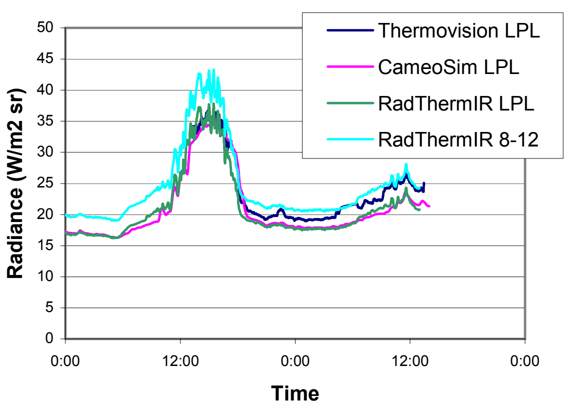

Figure 7 Comparisons of RadThermIR and CAMEO-SIM simulations and measurement results from Thermovision for the paint panel in the LW band. RadTherm LPL denotes a compensation to yield comparable results.

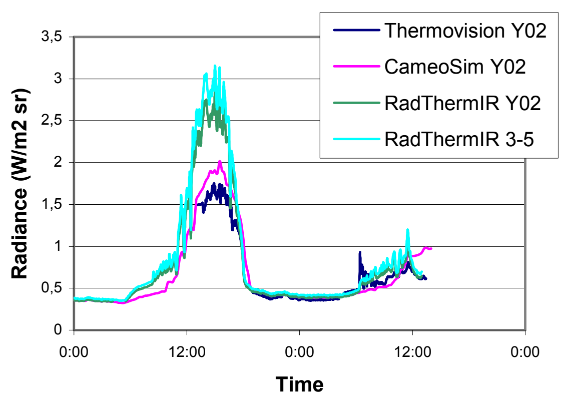

Figure 8 Comparisons of RadThermIR and CAMEO-SIM simulations and measurement results from Thermovision for the paint panel in the MW band. . RadTherm Y02 denotes a compensation to yield comparable results.

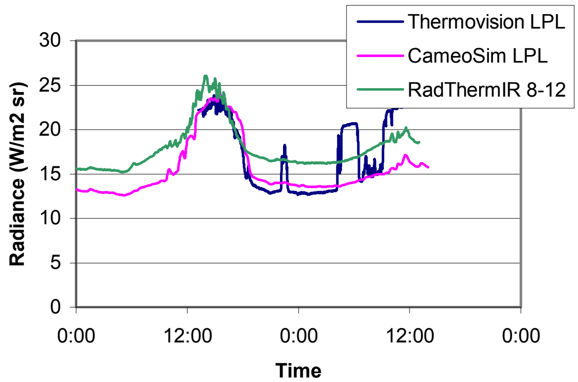

Figure 9 Comparisons of RadThermIR and CAMEO-SIM simulations and measurement results from Thermovision for the foil panel in the LW band. Note that RadThermIR results is in 8-12 µm.

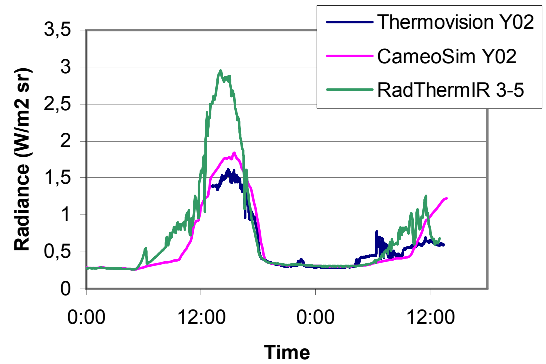

Figure 10 Comparisons of RadThermIR and CAMEO-SIM simulations and measurement results from Thermovision for the foil panel in the MW band. Note that RadThermIR results is in 3-5 µm.

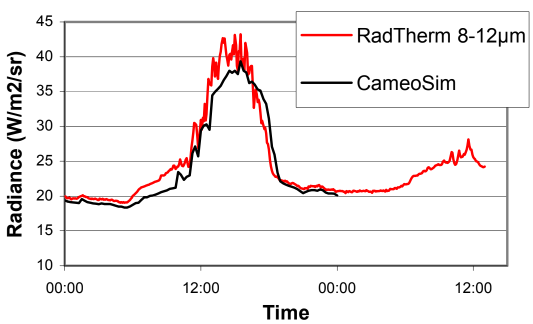

Figure 11 Comparisons of RadThermIR simulations and CAMEO-SIM simulations for the paint panel in LWIR. The response function is set to unity.

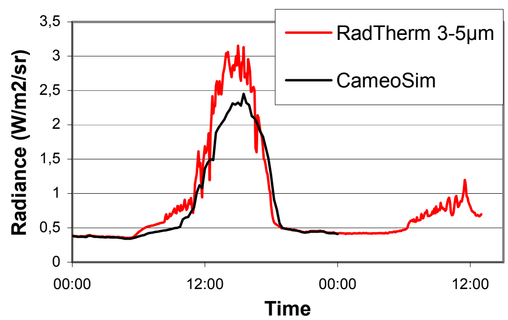

Figure 12 Comparisons of RadThermIR simulations and CAMEO-SIM simulations for the paint panel in MWIR. The response function is set to unity.

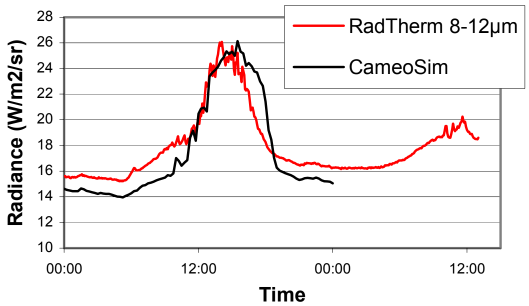

Figure 13 Comparisons of RadThermIR simulations and CAMEO-SIM simulations for the foil panel in LWIR. The respons function is set to unity.

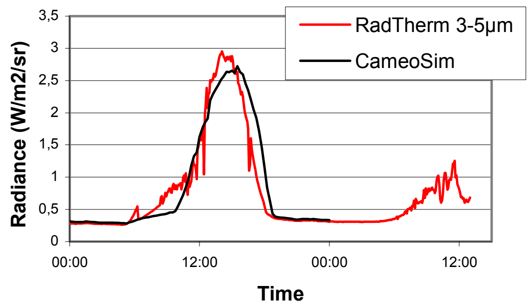

Figure 14 Comparisons of RadThermIR simulations and CAMEO-SIM simulations for the foil panel in MWIR. The respons function is set to unity.

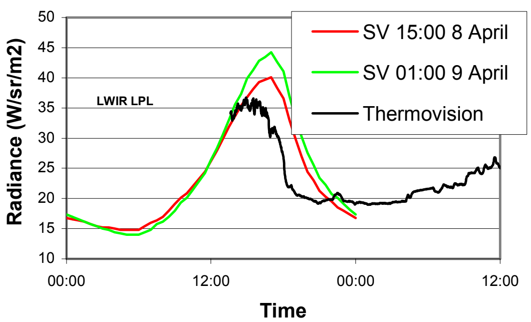

Figure 15 Comparisons of SensorVision simulations and measurement results from Thermovision for the paint panel. The SensorVision atmospheric model was calibrated at two different points of time.

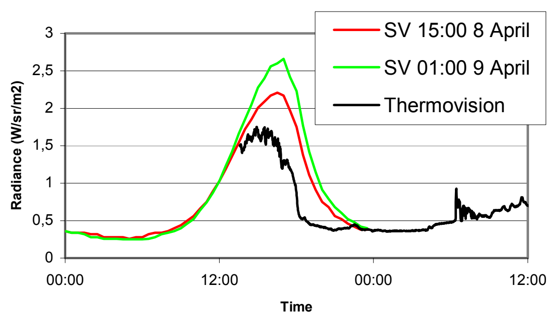

Figure 16 Comparisons of SensorVision simulations and measurement results from Thermovision for the paint panel. The SensorVision atmospheric model was calibrated at two different points of time.

6.0 DISCUSSION

From the plots presented in Section 5 we see that the accuracy of the predictions is varying and seem to be dependent on a number of factors. For instance, the accuracy varies between the three programs, the wavelength bands, the two panels and the time of day (including changes in weather). In general, a number of contributions to the discrepancy between measured and predicted values can be identified. Amongst these are errors and uncertainties in input data, errors and simplifications in the implemented models and errors and uncertainties in the measured data (see Section 2). All of these factors contribute to the discrepancy between measured and predicted values.

In the following sections we will make a few comments on the results obtained with the three simulation programs.

6.1 CAMEO-SIM

Results from simulations of the paint and foil panels are shown in Figure 5 - Figure 14 in Section 5. Since the known surface temperatures are a prerequisite for calculating the radiance, we first consider the comparison between predicted and measured surface (contact) temperatures shown in Figure 5 for the paint panel and in Figure 6 for the foil panel. We see that the predicted surface temperatures agree quite well with the measured contact temperatures. However, the measured contact temperatures are somewhat underestimated during daytime, something that is most noticeable for the panel with low emissive foil. The reason for this could, at least in part, lie in uncertainties in input data for the material parameters. For instance the values used for solar absorptivity, thermal emissivity and characteristic length for the convection are likely to have uncertainties which when combined are large enough to cover the discrepancy. Deficiencies in the models implemented in CAMEO-SIM of course also contribute to the prediction errors of surface temperatures. For instance, the modelling of convective heat transfer does not account for the details of the airflow around the object and there is no dependence on wind direction in the heat transfer coefficient used in CAMEO-SIM.

Another known source of error is, as was mentioned in Section 4.3, the fact that direct solar radiation input to CAMEO-SIM should not include diffuse scattered sun radiation. Furthermore, there was a problem with the sky radiation sensor on the weather station during the measurements. This had the consequence that the measured sky radiation data could not be used as input and the long wave sky radiation was instead calculated by MODTRAN4 in the CAMEO-SIM environment. Since this calculation was performed for clear sky conditions, the effects of clouds are not accounted for in the long wave sky irradiation on the panels. In version 5.0 of CAMEO-SIM the diffuse scattered sun radiation can be specified separately.

Considering the comparisons between measured and predicted radiance in Figure 7 - Figure 10, one should keep in mind that the errors in predicted temperatures are propagated, as one out of several sources of error, into the predicted radiance. We see from the figures that the calculated radiance generally agrees quite well with the measured data. The largest discrepancy is found during the second day (April 9) in the LWIR band for the panel with foil coating. As was mentioned in Section 2.4, the dramatic shifts in measured LWIR radiance from the foil panel during the night of April 9 is most likely an effect of changing cloudiness. A probable explanation for this discrepancy between calculations and measurements is the fact that the MODTRAN4 calculations in CAMEO-SIM were performed for clear sky conditions and therefore, the effect of varying cloud conditions are not accounted for in the reflected radiation from the panels. Since the panel with foil has a higher reflectance than the paint panel at IR wavelengths the effect is most noticeable for the foil coating.

6.2 RadThermIR and comparison with CAMEO-SIM

In Figure 7 - Figure 10 the predicted radiance is compared to the measured one. RADTHERM IR predicts the radiance in the wave band 3-5 µm and 8-12µm with unity responsivity. The measured data however, are reported for the Thermovision spectral responses LPL and Y02 seen in Figure 2. Therefore the values are not directly comparable. For the painted panels in Figure 7 and Figure 8 a correction is also included, valid for the assumption that the radiation origins from a blackbody. This is of course not completely true but gives a hint of what the correct level could be.

Many of the general comments made concerning the results obtained in the CAMEO-SIM simulations are also valid for the RADTHERM IR simulations. For instance, since the long wave IR sky radiation sensor on the weather station was out of order during the measurements, this component had to be modelled in RadTherm IR. Furthermore, as was the case in the CAMEO-SIM simulations, the radiometric calculations in RadTherm IR were performed for clear sky conditions and therefore the effect of varying cloud conditions are not accounted for in the reflected radiation from the panels. This is most clearly seen in Figure 9 for the panel with foil coating in the LWIR band.

We see from Figure 5 that the measured surface temperature was predicted rather well during most of the simulated period for the paint panel. For the panel with foil coating (Figure 6), on the other hand, the calculated surface temperatures clearly under-predict the measured temperatures during daytime, which is most noticeable April 8. A somewhat similar behaviour could be seen in the CAMEO-SIM but still it is difficult to conclude with any certainty whether the discrepancy is mainly due to uncertainties and errors in input data or deficiencies in models.

In Figure 11 - Figure 14 we compare the radiances calculated with RadTherm IR to the radiance obtained in the CAMEO-SIM calculations. In this comparison it should be noted that the response functions used in these CAMEO-SIM and Radthern IR is set to unity for 3-5 µm and 8-12 µm (compare with Figure 7 - Figure 10). Since the calculations for the panels have been performed in a similar way in CAMEO-SIM and RadTherm IR, the results obtained with the two programs are expected to agree quite well. From the figures we see that there is a clear correspondence between the results but there are also discrepancies. It is likely that there are many causes for these discrepancies. Differences in models, numerical algorithms and implementations in the two programs are obvious causes for differences in the results.

6.3 SensorVision

As was mentioned in Section 4.2, the SensorVision simulation does not use the full weather data history as input. Only a limited number of input weather data quantities can be set at a particular point in time in the thermal and atmospheric calculations performed in the tool MAT. This implies that the results depend on the choice of weather data calibration point and that the influence fluctuations in weather (for instance variations in wind speed, cloudiness, humidity, etc.) cannot be accounted for, resulting in a very smooth predicted radiance versus time. In Figure 15 and Figure 16 we can compare the results for two choices of calibration times and we see that the choice of calibration time affects the predicted radiance over time.

We notice from Figure 15 and Figure 16 that the measured radiance, in both wavelength bands, is over-predicted in the SensorVison simulations of the paint panel. This over-prediction stems from an over-prediction of surface temperatures in the tool MAT. We also see that there is a lag in time between the calculated radiance and the measured radiance for all simulation cases. For instance, the maximum predicted radiance is reached more than an hour later than the measured maximum radiance. This time lag seem stem from a time lag in the surface temperatures calculated in the tool MAT and no certain explanation for this discrepancy can be given at present.

SensorVision has real-time capacity and therefore several simplifications are necessary in the models. For a real-time application it is possible that the discrepancy is acceptable.

7.0 CONCLUSION

In this paper we have presented results from a measurement campaign as well as results from calculations, using the three IR signature programs SensorVision, CAMEO-SIM and RadThermIR. The calculations have been performed so as to simulate measurements of surface temperature and radiance from targets consisting of two panels with quite different surface emissivity. The simulations, using the three programs, have been compared with the measured data and with each other. Input data to the simulations consists of for instance measured spectral reflectance of the panel coatings, thermal material data, geometry, model parameters and measured weather data.

The comparison between measured and calculated radiance show an agreement, which generally can be said to be according to expectations for CAMEO-SIM and RadTherm IR, when considering the uncertainties in input data. In the case of SensorVision there seems to be a time lag between measured and predicted data which we can not explain at present.

We have tried to identify some possible causes for discrepancies between measured and predicted data. Some of the input data used in the simulations have uncertainties (or errors) which are likely to account for part of the discrepancies between measurements and predictions. Deficiencies in the models used in the programs are also likely to contribute to the prediction errors. We have also concluded that in the way the calculations were performed, the effect of changes in cloudiness (and other atmospheric conditions) is not accounted for in the radiation reflected from the panels. This resulted in rather large discrepancies between measured and calculated radiance from the panel with foil coating during times of changing cloud conditions.

The study presented in this report has provided insight and knowledge about the validity of predicting IR signatures using the three programs SensorVision, CAMEO-SIM and RadTherm IR. However, a continued work on validating the programs could give further information on their validity. For instance, it would be useful to perform a validation where the uncertainties in input data are accounted for in the simulations. The simulations could possibly also be performed in such a way that the actual cloud conditions are accounted for in a better way in the radiometric calculations. Validating the programs for other conditions and objects could also be of value.

Finally, one of the large benefits of a work like this is that it gives an opportunity to get really acquainted with the programs. They are all complex and require a lot of input data. There are also a considerable amount of settings in the programs that has to be made correctly in order to get reliable results. An exercise like the work presented in this report gives a possibility to use the programs under controlled conditions and to correct imperfections before more challenging simulations are made. The results in this report are encouraging and the programs will be applied to more complex targets and backgrounds.

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